

Modular Robotics for Delivering On-Site Contamination Sensors and Mapping Systems to Difficult-to-Access Locations

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by

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Introduction

A need exists throughout hundreds of facilities under the stewardship of the DOE to fully characterize and record the location of hazardous substances in order that these sites may be decontaminated and monitored. Presently, a variety of techniques and/or sensors for collecting and recording contaminant information exist.[5,6] Delivering these systems to the point of contamination often requires human effort that can be time consuming, hazardous to the worker and cost prohibitive due to the generation of secondary waste, the need for various forms of worker safety equipment and involved procedures. Additionally, the present quality of contamination surveys or “maps” is extremely coarse and subjective. Improvements in mapping techniques and data representation could allow for more accurate cleanup activities and would facilitate efforts associated with most D&D work.



Figure 1: Workers In Protective Gear Cleaning Contaminated Surfaces [4]

In light of this, a remote means of locating and accurately mapping contamination is required. To accomplish this with existing sensor technology, a mobile robotic system is needed which can be remotely operated to deliver a variety of sensors to specific points of contamination. Such a system would need to facilitate not only standoff sensor technologies, such as gamma imaging, but would allow for the more involved near-surface measurements to be taken and mapped as well. This “close-in” type of measurement adds significant complexity to the problem, and requires an extremely flexible, expedient robotic delivery system, given the varied makeup of contaminated sites. Fortunately, much of the base technology for such a system exists, and its integration into a useable “system” or “tool” will be the focus of this effort.

By using its modular approach to robotic systems, ARM Automation will provide one of many possible custom, portable and dexterous robotic systems for positioning sensors in a contaminated environment. This “Lego[®]-like” robot system will be mounted a mobile platform and equipped with cameras and other sensors which will enable a remote operator to quickly and safely designate numerous locations for semi-autonomous inspection and mapping.

Objective

Summary of Findings from an Investigation of the Characterization Practices and Needs of multiple DOE sites

During a phase 1 study of candidate test sites for this system, two main classes of characterization related to facility and equipment decommissioning and dismantlement were identified. The first relates to the characterization of contamination located in building surfaces and fixed equipment. The second class includes the inspection of movable equipment and scrap, such as machine tools, heat exchangers and boxed items, which must be disposed of, cleaned or otherwise handled. [2]

Both tasks share common needs and characteristics, some of which are:

- Limited knowledge of contaminant types and amounts
- Unknown contaminant locations
- Some high exposure areas or conditions
- Requirement to “prepare for the worst” in terms of personnel protective measures
- Necessity to wait for remote lab work results before proceeding

Building and fixed equipment characterization needs include:

- High walls and ceilings (some 40’(12m) high or more)
- Many obstructions such as equipment, pipes and structures
- Repeated characterization and monitoring
- Mapping of contamination for cleanup or long-term reference

Movable equipment characterization is typified by:

- Operation inside of a “hut” or environmentally controlled chamber
- Limited space and mobility around objects frequent
- Umbilicals must pass through sealed “ports” and must either be kept clean or cut at the threshold to the contaminated area

While there are a number of locations which are extremely difficult to access and survey, such as inside buried pipes and inside small cavities in process equipment, there are a much greater number of locations that are simply effort-intensive for a suited worker to safely access with standard practice. In the facilities surveyed, a large number of characterization tasks involve taking sample swipes from areas that require workers to crawl under, over, around or even into areas that are to be tested.

Limits of Existing Robotic Deployment Options

Conventional industrial robotic manipulator systems or “robotic arms” are generally designed to provide maximum speed and stiffness in a highly structured environment. As a consequence, these systems are massive and offer very limited reach for a given payload. A typical 6 axis (or Degree Of Freedom (DOF)) manipulator capable of carrying a 5.5kg (11lb) payload at a reach of 1.2m (3.9’) weighs approximately 160kg (350lb) not including system controller and umbilical which increase overall weight to

more than 295kg (650lb) [1]. This weight, along with bulky umbilicals and limited range of motion, severely limit the use of COTS robots in portable and remote systems.

Additionally, industrial robot systems are not designed for serviceability. Should a unit fail in the field, its monolithic design may not allow for repairs and can prohibit extrication. This is a known problem to the DOE and has even prompted funding of research for robot diagnostics [3]. Additionally, industrial robot systems are designed for use in relatively simple or pre-defined applications such as welding, spray painting or planar pick-and-place. For this reason, they do not facilitate the modifications or customization of hardware and controls required for complex integrated tasks, such as obstacle avoidance or automated world modeling.

Approach

To address the needs stated above, this project will address the limitations of remote robotic deployment systems and their integration with application-specific instruments to form usable tools. Under the current effort, a remotely operated mobile robotic platform and long-reach robotic arm are joined with a real-time radiological sensor system and contamination mapping system. The use of the dexterous, modular robotic system will enable the operator to semi-automatically position the sensor head to survey around objects, high along walls, on ceilings and inside confined spaces with proficiency beyond that of other approaches. With the long-reach (78" (2m) x 50" (1.3m)), dexterous arm now planned for initial demonstration, the system will be able to service approximately 50 times the workspace volume of off-the-shelf industrial manipulator capable of an equivalent payload (approximately 12 lb (5.4 kg))[1]. This greatly reduces required platform movements and opens up new opportunities for comprehensive remote surveys.

The entire mobile "cart" system will be capable of passing through standard (29") doorways and respectively will be able to access most any space designed for human entry. The slender "double jointed" manipulator arm (approximately 8" (200mm) in diameter) will also facilitate reach around objects and into limited-access spaces. However, under the system controller planned for this effort, some automated motion functionality will be limited during "reach in" applications due to visibility constraints.



Figure 2: Building Blocks of the ARM Modular Robotic Manipulator

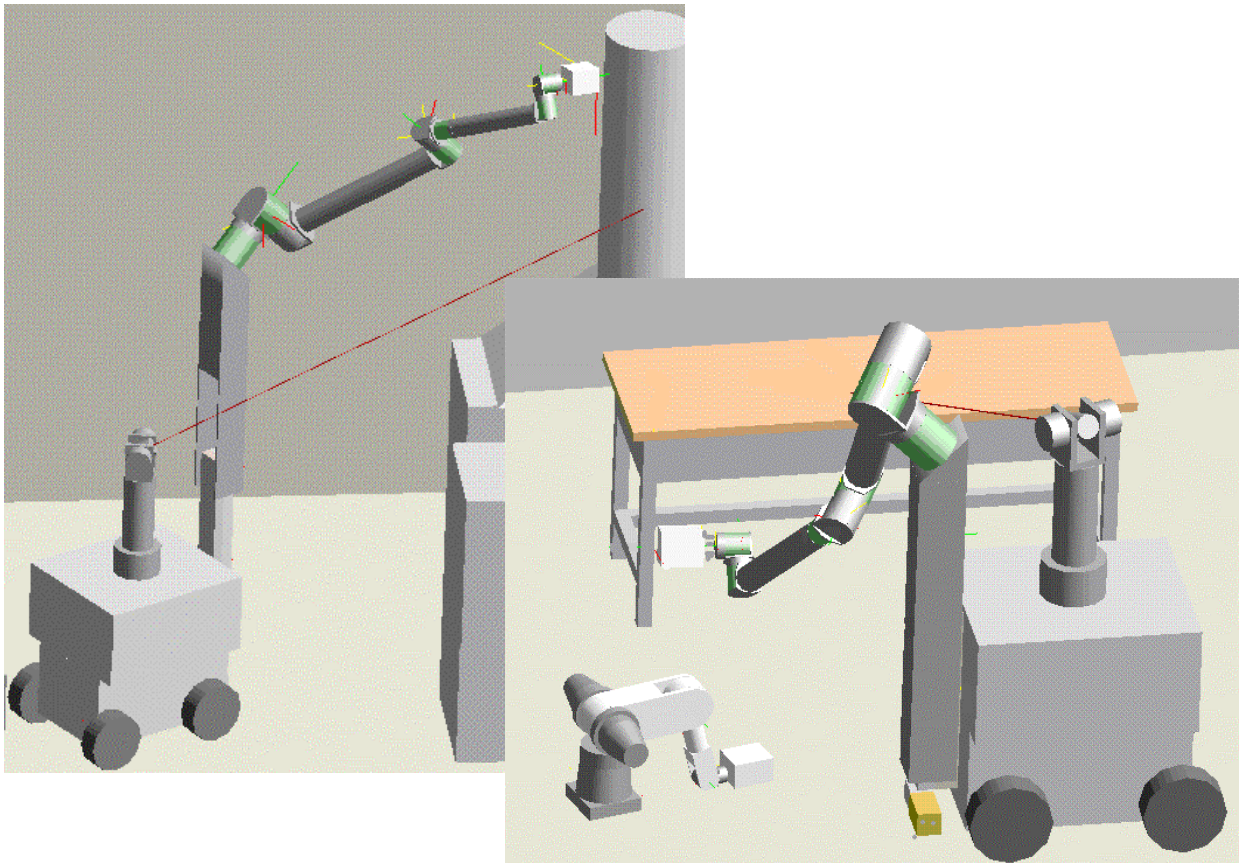


Figure 3: Remote Modular Robotic Characterization System

Key to the flexibility of the system is ARM Automation's modular robotic system. By combining, adding or subtracting different joint sizes and interconnecting links, users can readily adjust the robotic manipulator's shape and capabilities. The distributed communications used by the DISC (Distributed Intelligent Servo Controllers) located in each modular joint allows for a great reduction in wiring. This greatly simplifies maintenance and reduces points of failure in the system. In comparison to off the shelf manipulator systems, the portability of robots built from these building blocks is 4-5 times greater given their light weight/payload capacity.

Because of the system's near-surface measurement capabilities, this approach to characterization will allow for more accurate measurements of a wider variety of radiological source types than alternative remote or standoff sensing techniques. The system provides the user with the opportunity to designate surfaces with an onboard laser pointer/range finder device. Once one or more points are selected, the user can instruct the robotic system to automatically position the radiological sensor head at an accurate standoff distance for much longer periods of time than are feasible with humans. As some lower energy sources may take considerable time to collect sufficient data for an in-situ measurement, the system provides the opportunity for the operator to let the system work the surface at its own pace and over as many points as are required without necessitating long periods of worker entry and exposure to risk.

Improved data collection represents only half of the opportunity for improvement. Through a combination of information from the robotic positioning system, its laser pointer, intelligent sensors and camera system, this system will produce a 2-D graphical map of where contamination levels exist and in what concentration. Following a survey,

a graphical marker is superimposed upon a camera image of the surface to show workers exactly where various sources lie. Simple information such as magnitude may be represented directly on the image overlay, while more detailed data will be referenced by a marker corresponding to a separate record. By providing this visual image overlaid with data, subsequent cleanup or inspection efforts can refer to a positionally accurate representation of contamination sources as they work.

Basic Steps of Operation:

1. Initialization: This mode brings the system controller on line, allows for status checking, robot calibration and any sensor re-calibration, if necessary.
2. "Drive" mode: In this mode the mobile platform can be driven by a joystick on the remote user interface and camera system. In this mode the manipulator arm is disabled and stowed in the folded "safe" or home position. Once the operator positions the cart near the suspect area, they will use the pan/tilt camera positioner to examine and frame an area to be inspected. Once an area is "framed" in the CCD imaging system, the operator will enter the "Target" mode, and in doing so, will capture a camera image and lock out the pan/tilt unit and the cart's mobile base. (If they are deemed necessary for stability, outriggers will be deployed at this stage.)
3. "Target" mode: In this mode, the operator will again use the joystick to select targets with laser positioner mounted on the robot's end-effector. In this mode, the robotic manipulator is locked in a "mantis" position for stowage, such that the wrist is located in the up position. By moving the joystick, the operator can pan and tilt the laser to point at surfaces of interest in the field of view. Once a surface is designated, a measurement is taken which will provide the robotic system controller with the approximate coordinates of the surface of interest. If the location is outside of the robot's reach, the system controller will prompt the user to make another selection. The designated point information provides the robotic controller information needed for coarse positioning of the sensor by the robot arm and a visual indicator for the image processing system to identify the spot of interest on the image for data file association.
4. "Assay" mode: Once one or more points are selected by the user, the robot will make automatic moves first to a "safe" waypoint off the surface, and then, using feedback from multiple distance sensors, will approach the surface to the required standoff distance, which may vary from a foot or more down to a fraction of an inch. A measurement will then be made and the process will repeat from robot home, until complete. If the operator wishes this operation to be performed unattended (some sensors need long sample times) the operator may first "play through" the moves to verify the path is obstacle free.
5. "Review" mode: The user may then choose to review data collected and/or return to "Drive" mode to address new locations or camera views.

Projected Benefits

The combined system will enable users to quickly and cost-effectively configure and deploy task-specific robotic delivery mechanisms to accurately position sensors in hazardous environments with much greater reach and mobility than is practical using other robotic systems. This in-situ characterization approach can thereby eliminate much of the cost, time and waste associated with other characterization techniques such as the use of swipes, suited workers and the need for off-site laboratory facilities. Additionally,

with better, or more comprehensive data in hand, cleanup efforts can be streamlined to address only offending areas, saving wasted effort.

Some of the biggest savings may come from the time and cost associated with worker entries into contaminated, particularly uncharacterized, environments. By sending in a robotic system capable of taking a multitude of standoff and surface measurements, risks are reduced and many costly precautions avoided.[8,9,10]

While the end of this project will be marked by a demonstration in a specific facility, no two characterization tasks are alike and therefore a comparison to baseline will be site specific, and may not be representative of the gains to be made at every facility. Based upon a combined quantitative and qualitative survey taken during phase 1 of this project and time/motion simulations conducted thereafter, the following graphic represents some of the projected savings which could be made through the use of this system.

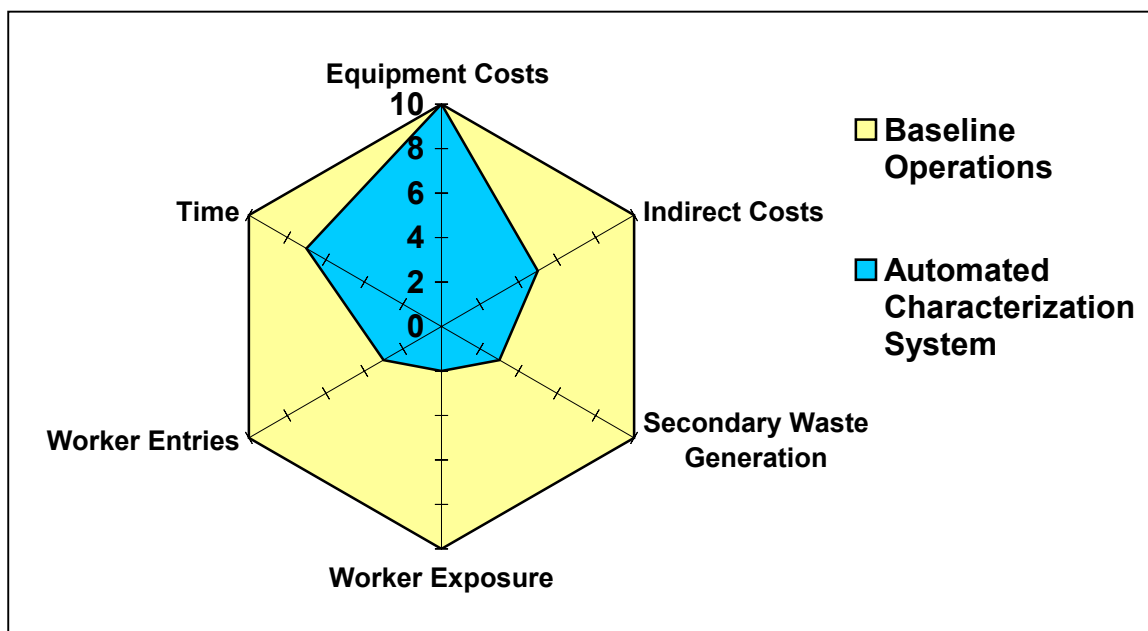


Figure 4: Projected Benefits VS. Prototypical Baseline [2]

Project Description

The development of this remote automated characterization system involves development in four key areas; the “cart” system, “modal” system control and user interfaces, contamination mapping software and development of an additional, larger size of modular actuator for an increased reach.

For the robot’s mobile base, ARM is evaluating the use of a 3rd party mobile robot chassis fitted with ARM Automation provided controls. Several vendors of mobile platform exist, however the field is greatly narrowed once payload, size and ability to operate over small obstacles are taken into consideration. This mobile platform will be used in a simple rate mode for this effort, and therefore requires relatively few technical developments beyond basic integration efforts.

Of greater challenge are the remote power and communications for the system. At present ARM is planning to operate the robot as a tetherless or wireless system. This greatly simplifies navigation and cabling issues and will open the door for many areas of future use beyond this application. A rechargeable battery system will power the platform and an upgraded version of ARM's SC5 system controller will be used for power management. The battery system is projected to provide for several hours of use under normal operating conditions.

Recent advances in wireless data network tools now make it feasible to operate the cart wirelessly within "earshot" of the control station. As the system controller will reside on the cart, only high-level command signals are carried between the operator terminal and the mobile system. Depending upon environmental conditions, wireless control of this system can be achieved up to distances of 800 ft. In addition, because this is a robotic system, a separate certified wireless safety stop switch shall also be used.

As with any application specific robotic system, significant effort will be put into the application, or supervisory, layer which resides on top of the basic robot controller. For this system, this layer will be referred to as the Modal Control System. This application layer will handle the various "modes" of operation, such as platform driving and robot "target" acquisition. This software will reside on the SC5 controller hardware and will take advantage of its "openness" to access relatively low-level control information effectively in real time.

In order to achieve some of the difficult reach tasks needed for this effort, a manipulator of greater length than could be supported by the ARM20 and ARM32 modules was needed. Therefore, one additional, larger size of actuator module will be developed to provide greater torque carrying capabilities and, thereby, a larger reach and payload capacity for this and future manipulator systems.

In order to produce effective "maps" of contamination locations and types, an image overlay system is produced. This software will take images from one of the available CCD cameras and overlay a graphical representation of where contamination lies on a surface. For more complete sensor data information, a numerical designator or label is superimposed next to each point of measurement. This label refers the user to the spectral analysis file.

Once complete, this system will undergo demonstration inside a designated DOE facility. During a phase 1 effort several DOE sites were evaluated and provided user specifications for the system. As a result of this effort, the Facilities Disposition Division of the Savannah River site have expressed their interest in testing and have identified a suitable location for demonstration. This facility contains small amounts of fixed contamination, has several difficult to access areas and may provide useful baseline information, given that it has previously undergone manual characterization efforts.

Accomplishments to Date

As of the writing of this paper, ARM is approximately 3 months into phase II of this project.

Working in conjunction with technical representatives of the Facilities Disposition Division of the Savannah River Site, a candidate facility has been identified which could

serve as a demonstration site. This former physics lab has undergone detailed characterization and cleanup, yet does still contain some amounts of fixed contamination. Such an area will provide a 'real-world' environment for testing and may allow for some comparisons to historical baselines for that facility. Additionally, sealed sources can be made available for "discovery" by the system, thus allowing the unit to remain uncontaminated during the demonstration.

A version of the SAM radiation monitoring system from Berkeley Nucleonics Corporation (in conjunction with Princeton Gamma Tech of Oak Ridge, TN) has been selected as one of the key sensors to be used by the robotic system. This device works with a single NaI detector unit to provide a portable radiological detector/analysis system that allows for quicker and more accurate isotope identification.

Several aspects of the mobile cart system, and subsystem components are now undergoing specification, procurement, build and testing. These systems will soon begin to come together as a mobile cart platform for system level testing. As one example, components of the laser range finding/targeting system have been procured and the development of software to control and communicate with the device has begun. As this system is built upon ARM's existing modular robot platform, some tests can be conducted on existing robotic manipulator equipment, thereby, accelerating the system integration and testing efforts.

The robot arm itself is undergoing further refinement and one new, larger actuator module size is now being designed. This larger joint will fill in the spectrum of "building blocks" that make up the modular "toolbox" for custom manipulators. With this larger joint, longer reaches and/or higher payloads can be achieved with these modular arms. The development of DISC electronics for the larger actuator size is also well underway. This includes cost reduction measures, which are intended to make it more feasible and attractive to potential customers, both in and outside of the DOE.

Future Activities

Beyond the goals of this project, which is slated for demonstration at the end of 2002, there are several paths forward for this system and its supporting technology in DOE cleanup activities and beyond. Over the long-term, several areas to be characterized will require follow-up inspection and long-term monitoring. This system and its improved documentation will facilitate such efforts. Because this mobile unit is also being designed to accommodate many types of sensor system, it can be retooled for use in a myriad of characterization applications and by changing robot geometry, the same basic tool can be used to conduct surveys inside a variety of environments.

The flexibility of a tetherless mobile modular robotic platform can also be readily applied to other remediation tasks such as sample collection or surface cleaning. ARM's ongoing work on other project areas includes the construction of manipulator arms suitable for deconstructive D&D tasks. One immediate potential opportunity is to use this same basic platform for torch cutting applications and material movement. In the future, because of its "openness", this system could readily incorporate current work in obstacle avoidance, such as that being conducted at the University of Tennessee and the University of Texas at Austin to enhance automated operation and streamline the process even further.

This effort also continues to provide support for small automation systems, such as those under development for automated nuclear material handling inside gloveboxes. This modular system is ideal for these purposes and ARM is continuing its efforts to work with the affiliated labs in their developing plans for this class of system.

In all, this work in modular automation systems and related efforts continues to be synergistic with, and support the common goals of DOE cleanup needs in a variety of areas.

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